Monitoring of fresh-cut spinach leaves through multispectral vision and sensory evaluation

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Abstract. *The aim of this work was to compare an image algorithm to detect changes in quality related with changes in leaf pigments content in leafy spinach during storage with a visual evaluation using a 1-4 scale, where 1 corresponds to fresh samples without any spoilage and 4 to samples with severe deterioration, in order to obtain a sensory evaluation index (I_{SE}) for each sample. The experiment was carried out on packed ready-to-use spinach stored at 4.5°C or 10ºC. Seventy-five leaves of spinach were analyzed at zero time and after 7, 14 and 21 days of storage at 4.5º C. Twenty-four e samples were measured at zero time and after 3, 6 and 9 days of storage at 10º C. Multispectral images were acquired in the red (R, 680±20 nm), infrared (IR, 800±20 nm) and blue (B, 450±20 nm) regions. Virtual images were calculated on the basis of spectral indexes usually employed for estimation of leaf pigment content. By considering the sensitive bands to chlorophyll, new virtual images were proposed. A non-supervised classification was applied to the obtained virtual images and the results were evaluated according to colorimetric measurements (CIE L*a*b* coordinates) and visual evaluation. Virtual images computed from R and B ranges gave the better results detecting changes in quality along period storage at 4.5º C. These virtual images were able to classify samples into two reference classes, including respectively the major part of the samples analyzed on zero time and on the 7th day and samples analyzed on the 14th and the 21th days.*

Keywords. Leaf vegetable; multispectral image; ready-to-use; visual evaluation

Introduction

It is well-known that processing of vegetables promotes a faster physiological deterioration of the product. For ready-to-use (RTU) spinach leaves, the major problem is the development of strong off-odor and discoloration (Allende et al., 2004). Regarding changes in colors, they are due to different biochemical processes involving plant pigments (Ferrante et al., 2004; Kader, 2002). Plant pigments can be estimated through non-destructive techniques, such as measurement of spectral reflectance, by employing indices based on opportune sensitive bands, i.e., red (660-700 nm), blue (450-480 nm), green (550 nm) and the near infrared (NIR) regions. However, spectrometers can analyze only small portions of the product and they can provide only an average color of the product (Abbott, 1999). Otherwise, computer vision systems (CVS) allow quantification based on the original appearance of the sample (Studman, 2001). The aim of this work was to evaluate quality of RTU spinach leaves through a CSV based on the cited sensitive bands and to compare the obtained results with reference parameters, i.e., color coordinates and a sensory evaluation index (I_{SE}).

Materials and methods

Spinach samples

Spinach used in this project was packed RTU baby spinach. Two experiments were carried out on two sets of samples. In the first one, spinach leaves were stored at 4.5°C and 85% HR; seventy-five units were evaluated per day: at zero time (treatment $t_{1.0}$) and after 7 (treatment $t_{1.1}$), 14 (treatment $t_{1.2}$) and 21 (treatment $t_{1.3}$) days of storage (*Set 1*, n = 300). In the second experiment, samples was stored at 10ºC for 9 days; twenty-four leaves were measured at zero time (treatment $t_{2.0}$) and after 3 (treatment $t_{2.1}$), 6 (treatment $t_{2.2}$) and 9 (treatment $t_{2.3}$) days (*Set 2*, n = 96).

Reference values

CIE L*a*b* color coordinates were obtained from the samples through a Minolta CM-50I portable spectrophotometer (Konica Minolta Sensing, Inc., Japan). Measurements were performed three times on one side of every spinach leaf. Deteriorating of the surfaces was also evaluated by three referees according to a visual color scale of 1–4, where 1 = fresh, without any spoilage, 2 = slight spoilage, 3 = severe deterioration, 4 = complete deterioration (Table 1).

A sensory evaluation index (I_{SE}) was obtained for each sample by averaging the three scores of the sensory panel. Color reference parameters and I_{SE} were compared to the classification based on the CSV. A mean comparison procedure (LSD test) was applied, with a significance level of 0.05. All analyses were carried out using a customized software application based in MATLAB® (MathWorks, Inc., USA).

Table 1. The 1-4 visual color scale employed in this work and some representative leaves.

Vision system and Image analysis

IRRB images were acquired for each sample through a 3-CCD camera endowed with three band-pass filters centered at 800±20 nm (infrared, IR), 680±20 nm (red, R), and 450±20 nm (blue, B). IRRB images were stored and processed off–line in MatLab®. At first, samples were distinguished from the background through the Otsu method, obtaining a binary image that was multiplied by the IR, R and B images and by the following virtual images: R/IR, (IR-R)/(IR+R), B/R and (R-B)/(R+B).

The last two image combinations were chosen in order to emphasize the possible changes in the image intensity related to the red band, which corresponds to the spectral region of one of the absorbance peak of chlorophyll, and to the blue region, where carotenoids and anthocyanins absorb particularly strongly. In this work, Index 1 (*Ind₁*), Index 2 (*Ind₂*), Index 3 (*Ind₃*), and Index 4 (*Ind₄*) were employed to refers to the R/IR, (IR-R)/(IR+R), B/R and (R-B)/(R+B) virtual images respectively.

A non-supervised classification according to Ward's method (Otto, 2007) was performed on the histograms computed on Ind_1, Ind_2, Ind_3 and Ind_4 virtual images in order to define deterioration reference classes (DRC). Each intensity level of the histogram was considered as a dimension of a multidimensional space, where a single histogram was represented as a single point. The matrix of Euclidean distances between each pair of individuals (histograms) was computed in order to group the closest ones and to hierarchically merge individuals whose combination gave the least Ward linkage distance. A MatLab® devoted code was developed in order to automatically generate groups on the basis of the input maximum Ward linkage distance. The average histogram was computed for each generated group and defined as DRC.

Results and discussion

Generation of deterioration reference classes

Fig. 1 shows an example of virtual images obtained by computing the Ind_1, Ind_2, Ind_3 and Ind_4 virtual images of one leaf spinach sample belonging to *Set 1* for different treatments.

From the non-supervised classification resulted that by setting the maximum *Ward Linkage distance* within groups at 0.5 pixel relative frequency for *Set 1* samples and at 0.3 pixel for *Set 2* samples, two clusters, corresponding to two DRC (Class A and Class B), were obtained for each virtual image. Table 2 reports the classification matrix obtained by applying the cluster analysis to each image combination of *Set 1* samples. The non-supervised classifications based on the Ind_3 and Ind_4 virtual images were able to segregate quite well between the storage periods: 93% of Class A was composed by samples measured at zero time and after 7 days of storage, and near 98% of Class B was composed by samples analyzed on the 14th and 21th days.On the otherwise, the classifications based on the Ind_1 and Ind_2 did no segregate so well the storage periods. The classification results regarding to *Set 2* samples were quite similar (table not shown), since Ind_3 and Ind_4 exhibited the best results: near 75% of Class A

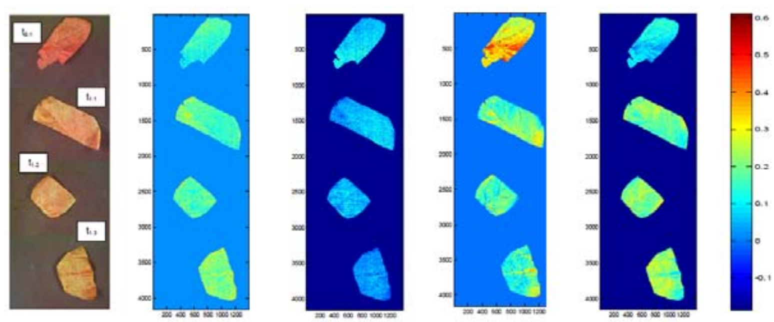

Fig. 1 – IRRB and virtual images (*Ind1*, *Ind2*, *Ind3* and *Ind4*, respectively) of a spinach leaf belonging to Set 1 calculated at zero time ($t_{1.0}$) and after storage for 7, 14 and 21 days ($t_{1.1}$, $t_{1.2}$ and $t_{1.3}$). Color scale represents intensity values of the images.

	Indices	Classes \ Treatments	OBSERVED	
			$t_{1.0}$- $t_{1.1}$	$t_{1.2}$-$t_{1.3}$
PREDICTED	Ind ₁	A	128	62
		B	22	88
	Ind ₂	A	114	33
		B	36	117
	Ind ₃	A	146	12
		B	4	138
	Ind ₄	A	148	13
		B	2	137

Table 2 - Classification matrix of Set 1spinach samples: treatments (observed classification) against reference camera classification (predicted classification).

was composed by samples analyzed on the first and the second day, while almost 70% of Class B was composed by samples analyzed on the 6th and 9th day, but the classifications based on the Ind_1 and Ind_2 was not so good

Color parameters of image based cluster

For both the sample sets, for each index and for each image-based cluster, a consistent increase was observed in L^*, b^* and I_{SE}, indicating change in black to white (L^*) and blue to yellow (b^*) color and an increasing deterioration in samples from Cluster A to B. The evolution trend of these values agreed with the results of previous studies that examined the evolution of color coordinates in spinach leaves during storage (Klockow and Keener, 2009). This means that the proposed classification was able to select proper classes (Clusters A and B) that could be considered quite homogenous in regards to color parameters and appearance. In both sets of samples, considering the four image-based classifications, Ind_3 and Ind_4 showed the best agreement between cluster classification and color parameters. On the basis of these results, image-based classes may provide relevant information for the management of RTU spinach leaves and has the potential to detect the most significant changes in color surface.

Conclusions

In the present study, a new method based on a multispectral vision system was proposed to classify leafy spinach on the basis of changes in colors related to quality deterioration. The classification method utilized relative histograms of four virtual images, e.g., Ind_1, Ind_2, Ind_3 and Ind_4 indexes, computed as combinations of infrared (IR, 800 nm), red (R, 680 nm) and blue (B, 450 nm) images. Virtual images computed from R and B ranges gave the better results detecting changes in quality along period storage at 4.5º C. These virtual images were able to classify samples into two reference classes, including respectively the major part of the samples analyzed on zero time and on the 7th day and samples analyzed on the 14th and the 21th days. In all cases, Class A to B presented increasing I_{SE}, L^*, a^* and b^* values, but image combination based on Ind_3 and Ind_4 showed the best sensitivity to reflect the change in colors associated with discoloration. This method could be used as a potential criterion for detecting the most significant color changes in RTU packed spinach leaves under refrigeration conditions with or without additional inhibitory treatments. In addition, this method allows for a more spatially detailed determination compared to other colorimetric techniques, which analyze a small portion of a sample and lead to errors and inaccurate results if the analysis is not repeated in different zones on the surface.

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Abbott, J.A., 1999. Quality measurement of fruits and vegetables Postharvest Biology and Technology 15(3):207-225.

Allende, A., Luo, Y., McEvoy, J.L., Artés, F., Wang, C.Y., 2004. Microbial and quality changes in minimally processed baby spinach leaves stored under super atmospheric oxygen and modified atmosphere conditions. Postharvest Biology and Technology 33(1):51-59.

Ferrante, A., Incrocci, L., Maggini, R., Serra, G., Tognoni, F., 2004. Colour changes of fresh-cut leafy vegetables during storage. Food, Agriculture & Environment 2(3-4):40-44.

Kader, A.A., 2002. Quality parameters of fresh-cut fruit and vegetable products, In: Lamikanra, O. (Ed.), Fresh-cut fruits and vegetables. CRC Press, Boca Raton, FL.

Klockow, P.A., Keener, K.M., 2009. Safety and quality assessment of packaged spinach treated with a novel ozone-generation system. LWT - Food Science and Technology 42(6):1047-1053.

Otto, M., 2007. Statistics and Computer Application in Analytical Chemistry. 2 ed, Chichester.

Studman, C.J., 2001. Computers and electronics in postharvest technology -- a review. Computers and Electronics in Agriculture 30(1-3):109-124.